

L-METHIONINE AS A STABILIZER FOR NESP/EPO IN HSA-FREE
FORMULATIONS

BACKGROUND OF THE INVENTION

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Due to recent advances in genetic and cell engineering technologies, proteins known to exhibit various pharmacological actions *in vivo* are capable of being produced in large amounts for pharmaceutical applications. Such proteins include erythropoietin (EPO), granulocyte colony-stimulating factor (G-CSF), interferons (alpha, beta, gamma, consensus), tumor necrosis factor binding proteins (TNFbp), interleukin-1 receptor antagonist (IL-1ra), brain-derived neurotrophic factor (BDNF), keratinocyte growth factor (KGF), stem cell factor (SCF), megakaryocyte growth differentiation factor (MGDF), osteoprotegerin (OPG), glial cell line derived neurotrophic factor (GDNF), obesity protein (OB protein), and novel erythropoiesis stimulating protein (NESP).

EPO is a glycoprotein hormone necessary for the maturation of erythroid progenitor cells into erythrocytes. It is produced in the kidney and is essential in regulating levels of red blood cells in the circulation. Conditions marked by low levels of tissue oxygen signal increased production of EPO, which in turn stimulates erythropoiesis. A loss of kidney function as is seen in chronic renal failure (CRF), for example, typically results in decreased production of EPO and a concomitant reduction in red blood cells. Human urinary EPO was purified by Miyake et al., *J. Biol. Chem.*, 252:5558 (1977) from patients with aplastic anemia. However, the amount of purified EPO protein obtained from this source was insufficient for therapeutic applications. The identification and

cloning of the gene encoding human EPO and expression
of recombinant protein was disclosed in U.S. Patent No.
4,703,008 to Lin, the disclosure of which is
incorporated herein by reference. A method for
5 purification of recombinant human erythropoietin from
cell medium is disclosed in U.S. Patent No. 4,667,016
to Lai et. al., which is incorporated herein by
reference. The production of biologically active EPO
from mammalian host cells has made available, for the
10 first time, quantities of EPO suitable for therapeutic
applications. In addition, knowledge of the gene
sequence and the increased availability of purified
protein has led to a better understanding of the mode
of action of this protein.

15 Both human urinary derived EPO (Miyake et al.
supra) and recombinant human EPO expressed in mammalian
cells contain three N-linked and one O-linked
oligosaccharide chains which together comprise about
40% of the total molecular weight of the glycoprotein.
20 N-linked glycosylation occurs at asparagine residues
located at positions 24, 38 and 83 while O-linked
glycosylation occurs at a serine residue located at
position 126 (see Lai et al., *J. Biol. Chem.*, 261:3116
(1986); Broudy et al., *Arch. Biochem. Biophys.*, 265:329
25 (1988)). The oligosaccharide chains have been shown to
be modified with terminal sialic acid residues with
N-linked chains typically having up to four sialic
acids per chain and O-linked chains having up to two
sialic acids. An EPO polypeptide may therefore
30 accommodate up to a total of 14 sialic acids.

Various studies have shown that alterations
of EPO carbohydrate chains can affect biological
activity. In one study, however, the removal of
N-linked or O-linked oligosaccharide chains singly or
35 together by mutagenesis of asparagine or serine

residues that are glycosylation sites sharply reduces
in vitro activity of the altered EPO that is produced
in mammalian cells; Dube et. al., *J. Biol. Chem.*,
263:17516 (1988). However, DeLorme et al.,

- 5 *Biochemistry*, 31:9871-9876 (1992) reported that removal
of N-linked glycosylation sites in EPO reduced *in vivo*
but not *in vitro* biological activity.

The relationship between the sialic acid
content of EPO and *in vivo* biological activity was
10 disclosed by determining the *in vivo* activity of
isolated EPO isoforms. It was found that a stepwise
increase in sialic acid content per EPO molecule gave a
corresponding stepwise increase in *in vivo* biological
activity as measured by the ability of equimolar
15 concentrations of isolated EPO isoforms to raise the
hematocrit of normal mice; Egrie et al., *Glycoconjugate*
J., 10:263 (1993). Those EPO isoforms having higher
sialic acid content also exhibited a longer serum half-
life but decreased affinity for the EPO receptor,
20 suggesting that serum half-life is an important
determinant of *in vivo* biological activity.

In the U.S., EPO has been used in the
treatment of chronic renal failure maintained on
dialysis as well as pre-dialysis, and in the treatment
25 anemia secondary to chemotherapy treatment in cancer
and in anemia associated with zidovudine treatment of
HIV infection. Worldwide, EPO has been used to treat
anemia associated with prematurity, sickle cell anemia,
rheumatoid arthritis, and bone marrow transplantation;
30 Markham et al., *Drugs*, 49:232-254 (1995).

NESP is a hyperglycosylated erythropoietin
analog having five changes in the amino acid sequence
of rHuEPO which provide for two additional carbohydrate
chains. More specifically, NESP contains two
35 additional N-linked carbohydrate chains at amino acid

residues 30 and 88 (numbering corresponding to the sequence of human EPO) (see PCT Application No. US94/02957, herein incorporated by reference in its entirety). NESP is biochemically distinct from EPO, 5 having a longer serum half-life and higher *in vivo* biological activity; Egrie et al., *ASH 97, Blood*, 90:56a (1997). NESP has been shown to have ~3 fold increase in serum half-life in mice, rats, dogs and man; Id. In mice, the longer serum half-life and 10 higher *in vivo* activity allow for less frequent dosing (once weekly or once every other week) compared to rHuEPO to obtain the same biological response; Id.

A pharmacokinetic study demonstrated that, consistent with the animal studies, NESP has a 15 significantly longer serum half-life than rHuEPO in chronic renal failure patients, suggesting that a less frequent dosing schedule may also be employed in humans; MacDougall, et al., *J American Society of Nephrology*, 8:268A (1997). A less frequent dosing 20 schedule would be more convenient to both physicians and patients, and would be particularly helpful to those patients involved in self-administration. Other advantages to less frequent dosing may include less drug being introduced into patients, a reduction in the 25 nature or severity of the few side-effects seen with rHuEPO administration, and increased compliance.

Although commercially available EPO and NESP formulations are generally well tolerated and stable, consideration should be given to the fact that, under 30 extreme conditions, such proteins may be unstable and undergo various undesirable physiochemical degradations during manufacturing, handling, and storage conditions. Such degradations include aggregation, inactivation, and oxidation of methionine residues, and such 35 degradations may be accelerated by external factors

such as heat and light, or in formulations that are free of human blood products such as albumin, or in multi-dose formulations which contain preservatives such as benzyl alcohol.

5 Methods of inhibiting oxidation in methionine-containing polypeptides have been described; Takruri et al., U.S. Patent No. 5,272,135 (December 21, 1993). Specifically, Takruri describes methods of inhibiting the oxidation of methionine residue(s) in
10 liquid or semi-liquid preparations, said preparations comprising polypeptides having amino acid sequences comprising at least one methionine residue. The prevention of methionine oxidation is said to be accomplished by the addition of free L-methionine to
15 the preparations in an amount sufficient to inhibit oxidation of the methionine residue(s) in the polypeptide. The oxidation of the methionine residues is said to be associated with the plastic containers, e.g., polypropylene or low density polyethylene (LDPE),
20 which are readily permeable to oxygen, and within which the preparations are stored. The polypeptides contemplated for use in Takruri are growth factors, and the preparations tested are ophthalmic aqueous-based preparations of epidermal growth factor (EGF).
25 Preparations containing EPO or NESP, or any other glycosylated protein are not discussed, nor are formulations which are HSA-free, multi-dose, or HSA-free multi-dose discussed.

30 SUMMARY OF THE INVENTION

 The present invention provides pharmaceutical formulations of EPO and/or NESP wherein the incorporation of methionine and other stabilizing
35 agents into said formulations provide for a more stable

formulation, even in extreme conditions wherein critical degradations induced by light, heat, impurities in additives, leacheates in the prefilled syringes, the manufacturing process, storage, transportation, and handling may otherwise occur.

Importantly, the formulations also demonstrate improved stability in HSA-free formulations and HSA-free multi-dose formulations containing preservatives, wherein the critical degradations may be more pronounced.

BRIEF DESCRIPTION OF THE DRAWINGS

Figure 1 is a graph depicting the effect of free methionine on the aggregation of NESP during exposure to light. NESP in phosphate buffered saline was exposed to ultraviolet light for 4 hours at room temperature.

Figure 2 is a graph depicting the effect of free methionine on the aggregation of NESP in the presence of 1% benzyl alcohol during storage at 2-8°C. Samples containing 500 µg/mL of NESP were stored for 13 months.

Figure 3 is a graph depicting the effect of various additives and treatment on the oxidation of methionine 54 residue in NESP during incubation for 90 days at 37°C. % oxidation was determined by tryptic mapping followed by Reversed-phase HPLC and mass spectrometry.

Figure 4 is a graph depicting the effect of free methionine on the oxidation of NESP in a preserved

formulation containing 1% benzyl alcohol. 0-20mM free methionine was tested and samples were incubated at 4°C for 56 days.

5 Figure 5 is a graph depicting the effect of free methionine on the oxidation of NESP in a preserved formulation containing 1% benzyl alcohol. 0-20mM free methionine was tested and samples were incubated at 29°C for 56 days.

10 Figure 6 compares the tryptic maps of EPO in solutions at pH 7.0 \pm benzyl alcohol and \pm free L-methionine.

15 Figure 7 is a graph comparing NESP methionine oxidation rates with and without purging (10 minutes) with nitrogen. % methionine oxidation is plotted versus benzaldehyde concentration. 0.1 mg/ml NESP was tested.

20 Figure 8 compares the tryptic maps of over-oxidized NESP samples. Met-54 was fully oxidized for all samples shown in the figure. Numbers depicted on the figure represent the concentration of methionine added to the samples.

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DETAILED DESCRIPTION OF THE INVENTION

30 "Excipient" is defined herein as a non-therapeutic agent added to a pharmaceutical composition to provide a desired effect, e.g. stabilization, isotonicity.

35 "Polypeptide" is defined herein as natural, synthetic, and recombinant proteins or peptides having more than about 10 amino acids, and having a desired biological activity.

As used herein, biologically active agents refers to recombinant or naturally occurring polypeptides, whether human or animal, useful for prophylactic, therapeutic or diagnostic application.

5 The biologically active agent can be natural, synthetic, semi-synthetic or derivatives thereof. Contemplated active agents include peptides, small molecules, carbohydrates, nucleic acids, lipids, proteins, and analogs thereof. One skilled in the art
10 will readily be able to adapt a desired biologically active agent to the compositions of present invention.

Proteins contemplated for use would include but are not limited to interferon consensus (see, U.S. Patent Nos. 5,372,808, 5,541,293 4,897,471, and
15 4,695,623 hereby incorporated by reference including drawings), granulocyte-colony stimulating factors (see, U.S. Patent Nos. 4,810,643, 4,999,291, 5,581,476, 5,582,823, and PCT Publication No. 94/17185, hereby incorporated by reference including drawings),
20 interleukins (see, U.S. Patent No. 5,075,222, hereby incorporated by reference including drawings), erythropoietins (see, U.S. Patent Nos. 4,703,008, 5,441,868, 5,618,698 5,547,933, and 5,621,080 hereby incorporated by reference including drawings), stem
25 cell factor (PCT Publication Nos. 91/05795, 92/17505 and 95/17206, hereby incorporated by reference including drawings), osteoprotegerin (PCT Publication No. 97/23614, hereby incorporated by reference including drawings), novel erythropoiesis stimulating
30 protein (NESP) (PCT Publication No. 94/09257, hereby incorporated by reference including drawings), leptin (OB protein) (see PCT publication Nos. 96/40912, 96/05309, 97/00128, 97/01010 and 97/06816 hereby incorporated by reference including figures),
35 megakaryocyte growth differentiation factor (see, PCT

Publication No. 95/26746 hereby incorporated by
reference including figures), tumor necrosis factor-
binding protein (TNF-bp), interleukin-1 receptor
antagonist (IL-1ra), brain derived neurotrophic factor
5 (BDNF), glial derived neurotrophic factor (GDNF),
keratinocyte growth factor (KGF) and thrombopoietin.
The term proteins, as used herein, includes peptides,
polypeptides, consensus molecules, analogs, derivatives
or combinations thereof.

10 In general, EPO useful in the present
invention has the sequence of human erythropoietin, or
closely related analogues thereof. The EPO may be
produced by mammalian cells outside the body, or it may
be isolated from natural sources. Preferably, the EPO
15 is recombinant human EPO (rHuEPO) produced as described
in U. S. Patent No. 4,703,008 to Lin, the disclosure of
which is incorporated herein by reference. The amino
acid sequence of EPO is that depicted herein in SEQ ID
NO:1. The preferred host cells are Chinese Hamster
20 Ovary (CHO) cells as described in Example 10 of the Lin
patent. Other host cells known in the art, e.g. baby
hamster kidney cells, may also be used to produce EPO
useful in the present invention. While the procedures
of Example 10 in the Lin patent are the preferred
25 method for producing rEPO, modifications and changes
could be made to that process as known in the art.

NESP of the present invention is a
hyperglycosylated EPO analog comprising two additional
glycosylation sites with an additional carbohydrate
30 chain attached to each site. NESP was constructed
using site-directed mutagenesis and expressed in
mammalian host cells. Details of the production of
NESP are provided in co-owned PCT Application No.
US94/02957. New N-linked glycosylation sites for
35 rHuEPO were introduced by alterations in the DNA

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sequence to encode the amino acids Asn-X-Ser/Thr in the polypeptide chain. DNA encoding NESP was transfected into Chinese Hamster Ovary (CHO) host cells and the expressed polypeptide was analyzed for the presence of additional carbohydrate chains. In a preferred embodiment, NESP will have two additional N-linked carbohydrate chains at residues 30 and 88. The numbering of the amino acid sequence is that of human erythropoietin (EPO). The amino acid sequence of NESP is that depicted herein in SEQ ID NO:2. It is understood that NESP will have the normal complement of N-linked and O-linked glycosylation sites in addition to the new sites.

The EPO and NESP of the present invention may also include conservative amino acid changes at one or more residues in SEQ ID NOs:1 and 2. These changes do not result in addition of a carbohydrate chain and will have little effect on the biological activity of the analog. These are set forth in Table 1, below. See generally, Creighton, *Proteins, passim* (W.H. Freeman and Company, N.Y., 1984); Ford et al., *Protein Expression and Purification* 2:95-107 (1991), which are herein incorporated by reference.

25

Table 1

Conservative Amino Acid Substitutions

Basic:	arginine lysine histidine
Acidic:	glutamic acid aspartic acid
Polar:	glutamine asparagine

Hydrophobic:	leucine isoleucine valine
Aromatic:	phenylalanine tryptophan tyrosine
Small:	glycine alanine serine threonine methionine

Therapeutic uses of the compositions of the present invention depend on the biologically active agent used. One skilled in the art will readily be able to adapt a desired biologically active agent to the present invention for its intended therapeutic uses. Therapeutic uses for such agents are set forth in greater detail in the following publications hereby incorporated by reference including drawings.

Therapeutic uses include but are not limited to uses for proteins like consensus interferon (see, U.S. Patent Nos. 5,372,808, 5,541,293, hereby incorporated by reference including drawings), interleukins (see, U.S. Patent No. 5,075,222, hereby incorporated by reference including drawings), erythropoietins (see, U.S. Patent Nos. 4,703,008, 5,441,868, 5,618,698, 5,547,933, 5,621,080, 5,756,349, and 5,955,422, hereby incorporated by reference including drawings), granulocyte-colony stimulating factors (see, U.S. Patent Nos. 4,999,291, 5,581,476, 5,582,823, 4,810,643 and PCT Publication No. 94/17185, hereby incorporated by reference including drawings), megakaryocyte growth differentiation factor (see, PCT Publication No. 95/26746), stem cell factor (PCT Publication Nos.

91/05795, 92/17505 and 95/17206, hereby incorporated by
reference including drawings), OB protein (see
PCT publication Nos. 96/40912, 96/05309, 97/00128,
97/01010 and 97/06816 hereby incorporated by reference
5 including figures), and novel erythropoiesis
stimulating protein (PCT Publication No. 94/09257,
hereby incorporated by reference including drawings).
In addition, the present compositions may also be used
for manufacture of one or more medicaments for
10 treatment or amelioration of the conditions the
biologically active agent is intended to treat.

As relates specifically to NESP, the present
invention provides for a method of raising and
maintaining hematocrit in a mammal comprising
15 administering a therapeutically effective amount of
NESP in a pharmaceutical composition of the present
invention, wherein the NESP is administered less
frequently than an equivalent molar amount of rHuEPO to
obtain a comparable target hematocrit. The dosing
20 frequency of the present invention in order to reach a
patient's optimal hematocrit range is less than three
times per week. Dosing frequencies may be two times
per week, one time per week, or less than one time per
week, such as one time every other week, once per month
25 or once every two months. The dosing frequency
required to maintain a patient's target hematocrit is
less than three times per week. Dosing frequencies may
be two times per week, one time per week, or less than
one time per week, such as one time every two weeks,
30 once per month or once every two months.

The invention may be employed with any
condition resulting in a decrease in red blood cell
levels, such as anemia associated with a decline or
loss of kidney function, (chronic renal failure)
35 myelosuppressive therapy, cancer, viral infection,

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chronic disease and excessive loss of blood during surgical procedures.

It is envisioned that the formulations of the present invention will additionally contain a buffering agent, e.g., alkali salts (sodium or potassium phosphate or their hydrogen or dihydrogen salts), sodium citrate/citric acid, sodium acetate/acetic acid, and any other pharmaceutically acceptable ph buffering agent known in the art, to maintain the pH of the solution within a desired range. Mixtures of these buffering agents may also be used. The amount of buffering agent useful in the composition depends largely on the particular buffer used and the pH of the solution. For example, acetate is a more efficient buffer at pH 5 than pH 6 so less acetate may be used in a solution at pH 5 than at pH 6. The preferred pH of the preferred formulations will be in the range of 5.0 to 7.0, and pH-adjusting agents such as hydrochloric acid, citric acid, sodium hydroxide, or a salt thereof, may also be included in order to obtain the desired pH.

The formulations will also contain sorbitan mono-9-octadecenoate poly(oxy-1,2-ethanediyl) derivatives, including but not limited to, polysorbate 80 or polysorbate 20. Other derivatives are well known in the art. The amount of polysorbate 20 or 80 to be used will be in the range of 0.001% to 0.1% (w/v). The preferred amount is 0.005% (w/v) in the single use and multi-dose formulations.

In order to provide EPO and/or NESP pharmaceutical formulations having superior stability, free L-methionine will be included in the formulations. The amount of free L-methionine included will be in the range of 0.05mM to 50mM. In HSA-containing formulations, the preferred amount in the single use formulations is 0.05mM to 5mM, and the preferred amount

in the multi-dose formulations is 1mM to 10mM. In HSA-free formulations, the preferred amount in the single use formulations is 0.05mM to 5mM, and the preferred amount in the multi-dose formulations is 1mM to 10mM.

5 Preservatives contemplated for use in the multi-dose formulations of the present invention include benzyl alcohol, benzalkonium chloride, chlorobutanol, cresol, phenol, and parabens. The amount of preservative included will be in the range of
10 0% to 2% (w/v) and the preferred amount in the formulations is 1% (w/v).

 The formulations of the present invention may further include an isotonicity adjusting agent to render the solution isotonic and more compatible for
15 injection. Typical tonicity agents are well known in the art and include but are not limited to sodium chloride, mannitol, glycine, and sorbitol. The preferred agent is sodium chloride within a concentration range of 0mM to 200mM.

20 It is also envisioned that other anti-oxidants may be included in the formulations of the present invention. Anti-oxidants contemplated for use in the preparation of the formulations include amino acids such as glycine and lysine, chelating agents such
25 as EDTA and DTPA, and free-radical scavengers such as sorbitol and mannitol.

 Preferred NESP formulations contemplated for use in the present invention will contain 10mM to 30mM phosphate buffer, 100mM to 200mM NaCl, 0.001% to
30 0.1%(w/v) polysorbate 80, and 0.5mM to 50mM L-methionine, pH 5.0-7.0; and more preferably, 20mM phosphate buffer, 140mM NaCl, 0.005%(w/v) polysorbate 80, and 1mM L-methionine, pH 6.2.

 Preferred EPO formulations contemplated for
35 use in the present invention will contain 0.01mM to 5mM

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phosphate buffer, 0.01mM to 150mM NaCl, 5mM to 50mM
L-arginine or L-histidine or salt thereof, 0.001% to
0.1% (w/v) polysorbate 80, and 0.5mM to 50mM
L-methionine, pH 5.0-7.0; and more preferably, 2mM
5 phosphate buffer, 110mM NaCl, 43.1mM L-arginine HCl,
0.006 % (w/v) polysorbate 80, and 0.5, 1, 2, 3 or 5mM
L-methionine, pH 6.0; or 2mM phosphate buffer, 142mM
NaCl, 9.54mM L-histidine HCl, 0.006% (w/v) polysorbate
80, and 0.5, 1, 2, 3 or 5mM L-methionine, pH 6.0.

10 Also contemplated for use in inhibiting
oxidation of methionine is nitrogen overlay. Nitrogen
overlay can be introduced to the headspace of a vial or
prefilled syringe by purging nitrogen during the
filling process.

15 The following examples are offered to more
fully illustrate the invention, but are not to be
construed as limiting the scope thereof.

20 Example 1

This example describes the preparation of EPO
and NESP HSA containing and HSA-free single use and
multi-dose formulations. The EPO and NESP protein
25 preparations were prepared as described in the
Materials and Methods section below.

NESP and/or EPO HSA-containing formulations
were then prepared by adding 0.1-1% albumin, the
appropriate buffering agents (e.g., sodium phosphate),
30 and a tonicity modifier (e.g., sodium chloride) to the
protein preparation to obtain formulations having the
desired concentrations of protein and excipients. NESP
and/or EPO HSA-free formulations were prepared by
replacing the albumin with other recombinant proteins
35 or pharmaceutically acceptable surfactants (e.g.

polysorbate 20 or 80). Multi-dose formulations were prepared by introducing preservative(s) (e.g. benzyl alcohol) to the HSA-containing or HSA-free formulations.

5

Example 2

This example describes experiments wherein the effect of free L-methionine on the aggregation (introduced by light) of NESP was evaluated. Although the underlying mechanism is not clear, under extreme conditions, light introduces significant aggregation to the NESP formulations. NESP single use, HSA-free formulations prepared as described in Example 1 were used in the experiment.

The glass vials containing the protein were placed into a UV light box and were incubated overnight (16 hours) with continuous UV light exposure. The samples were analyzed with SEC-HPLC. As depicted in Figure 1, addition of 10mM free methionine significantly decreased the rate of aggregation.

Example 3

This example describes experiments wherein the effect of free L-methionine on the aggregation of NESP in the presence of benzyl alcohol was evaluated. Although the underlying mechanism is not clear, benzyl alcohol introduces very minor aggregation to the NESP formulations even during storage at 2-8°C. NESP multi-dose, HSA-free formulations prepared as described in Example 1 were used in the experiment.

Multi-dose formulations containing 1% benzyl alcohol were incubated for 13 months at 2-8°C and analyzed with SEC-HPLC method. As depicted in Figure

2, addition of 1mM-20mM free methionine significantly decreased the rate of aggregation.

Example 4

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This example describes experiments wherein various additives and treatments were tested for their ability to inhibit methionine oxidation in the NESP HSA-free single use formulations. NESP HSA-free single use formulations prepared as described in Example 1 were used in the experiments.

10

First, the protective effect of various anti-oxidants on NESP was examined by hydrogen peroxide spiking experiment (described in the Materials and Methods section below). Free amino acids L-lysine, glycine and L-methionine were tested and the % oxidation was determined by tryptic mapping as described in the Materials and Methods section below. It was demonstrated convincingly that free L-methionine prevents the oxidation of the Met-54 residue of NESP in the presence of excess hydrogen peroxide (see Table 1).

15

20

Table 1

25

30

<u>Anti-Oxidant</u>	<u>NESP Met-54 Oxidation (%)</u>
Glycine	100
Lysine	100
Methionine	37.3
Glycine + Lysine	100
Glycine + Methionine	35.3
Lysine + Glycine + Methionine	32.9

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Next, the protective effect of various additives and treatments on NESP was examined. A NESP HSA-free formulation was used as a control. Additives tested were 20mM L-Methionine, 10mM histidine and 0.1mM EDTA. Nitrogen overlay in the head space was also

evaluated. It was determined that free L-Methionine, EDTA, histidine, and/or nitrogen overlay can effectively inhibit the oxidation of Met-54 residue of NESP HSA-free formulations against various oxidative agents such as peroxide, superoxide ions (see Figure 3). The combination of free L-Methionine with either EDTA or histidine was more effective in inhibiting the oxidation than individual additives (see Figure 3). The combination of free L-Methionine and nitrogen overlay in the head space was also more effective in individual treatment (see Figure 3).

Example 5

This example describes experiments wherein various additives and treatments were tested for their ability to inhibit methionine oxidation in EPO and/or NESP HSA-free multi-dose formulations. EPO and/or NESP HSA-free multi-dose formulations prepared as described in Example 1 were used in the experiments.

First, the protective effect of various concentrations of free L-Methionine on NESP HSA-free multi-dose formulations was examined by hydrogen peroxide spiking experiments as described in Example 2. The formulations contained 1% benzyl alcohol and free methionine concentrations ranging from 0-20mM were tested. Samples were incubated for 56 days at either 4°C or 29°C. The addition of free L-Methionine was found to be effective in inhibiting the oxidation induced by benzyl alcohol impurity in the multi-dose formulation (see Figures 4 and 5).

Next, the effect of methionine on HSA-free EPO formulations \pm benzyl alcohol was evaluated. Figure 6 compares the tryptic maps of EPO in solutions

with and without benzyl alcohol, and it is clear that the addition of this particular lot of benzyl alcohol can lead to nearly complete oxidation of EPO in solution at pH 7.0. However, the addition of free L-Methionine can completely prevent the oxidation of EPO in a solution containing the same benzyl alcohol.

In addition, it was determined that purging the buffer solution with nitrogen could also significantly reduce the rate of Met-54 oxidation of NESP by benzaldehyde (see Figure 7). This indicates that free L-Methionine can inhibit the oxidative effect of dissolved molecular oxygen on Met-54 of NESP.

Example 6

This example describes experiments wherein the effect of methionine 54 oxidation on the biological activity of NESP was evaluated. First, NESP formulations were oxidized with 0.01% hydrogen peroxide for different duration such that NESP samples containing different amounts of oxidized methionine 54 residue could be obtained. It was determined that the oxidation of methionine 54 does not adversely affect biological activity of NESP or EPO (see Table 2).

Table 2

	<u>Oxidation (%)</u>	<u>Activity (%)</u>	
		<u>In vitro</u>	<u>in vivo</u>
	Control	121	121
	15	92	133
	39	95	125
	57	90	109
	76	102	100
	100	95	106

Next, a sufficient concentration of hydrogen peroxide was added and the samples incubated for

several days such that all the methionine 54 residue in the NESP solution are oxidized even in the presence of added free L-methionine. It was determined that under extreme oxidative stress, NESP loses biological activity, in that samples that did not contain free methionine lost significant biological activity (see Table 3).

Table 3

Sample	Methionine Oxidation (%)	Activity (%)
0mM Met, 0.25% H ₂ O ₂ , 6 days	100	37
5mM Met, 0.25% H ₂ O ₂ , 6 days	100	85
10mM Met, 0.25% H ₂ O ₂ , 6 days	100	91
20mM Met, 0.25% H ₂ O ₂ , 6 days	100	85
40mM Met, 0.25% H ₂ O ₂ , 6 days	100	77

The inactivation of NESP was ascribed to the oxidation of other residues than methionine. Tryptophan, cysteine, and histidine were identified as additional oxidation sites (see Figure 8). Addition of free methionine prevents the oxidative inactivation of NESP by protecting these critical amino acids from oxidation (Table 3).

Materials and Methods

The EPO used in the present invention may be prepared according to the above incorporated-by-reference U.S. Patent No. 4,703,008 (Lin).

The NESP used in the present invention may be prepared according to the above incorporated-by-reference PCT Publication No. 94/09257.

Tryptic mapping of NESP or EPO was carried out by digesting the proteins with commercially available trypsin followed by separation of peptides

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